An e-cigarette smoking machine for nonroutine analyses

J.H. Lauterbach and S.J. Lauterbach
Lauterbach & Associates, LLC, Macon, GA 31210-4708 USA

Abstract

Over the past few years, several commercial laboratories have established capabilities for testing the aerosols generated by e-cigarettes. These laboratories have used test procedures and instrumentation that are likely to become generally recognized methods for the analysis of aerosols generated by e-cigarettes. However, the technology associated with the design and manufacture of e-cigarettes and the formulation of e-liquids is rapidly changing, and new analytical techniques are needed for understanding the underlying science of current and future generations of e-cigarette products. In some cases, these techniques require or will require downstream analytical techniques that are not compatible with existing smoking machines because of space requirements and/or the need for reagents that may interfere with the proper operation of conventional smoking machines. Consequently, we have designed, built, and tested a four-port e-cigarette smoking machine for nonroutine analyses of e-cigarette aerosols. We have expanded on the machine design we employed for the measurement of e-cigarette aerosol temperatures (CORESTA Congress 2014, ST41) using features from constant-vacuum smoking machines designed by A. B. Canon and reported in 1976 (http://industrydocuments.library.ucsf.edu/tobacco/docs/gllb0093) and by J. R. Newsome *et al*., and first reported in 1963 (Tob. Sci. 1965 9:102-110). We will report the basic operating parameters of our machine and its use for aerosol stream-visualization, aerosol derivatization (for example., persilylation of TPM with BSTFA/TMCS), and GC-MS characterization of the derivatiized and underivatized aerosols generated under normal and so-called "dry-puffing" conditions.

Introduction

A presentation at the 67th Tobacco Science Research Conference on smoking machine variables that effected the TPM yield of e-cigarettes showed that a square-wave puff would likely be more appropriate for e-cigarettes than the bell-shaped puff used for conventional cigarettes (Connor, 2013). This finding opened up a new avenue for the construction of smoking machines without the complexity of machines designed to produce a bell-shaped puff. Indeed, the approach was not new, but had been used several decades in the past, as it was simple to build what was called a constant-vacuum (CV) smoking machine. All one needed was a vacuum source, a electrical timer and solenoid valve, a critical flow orifice (CFO), and a way of affixing the smoke trap to the CFO. More complex CV smoking machines were developed by Newsome *et al*. (1965) and Claflin and Watson (1977).

Introduction (con't)

The driving force for the development of our own e-cigarette smoking machine was the lack of capabilities available at commercial testing laboratories for doing nonroutine analyses on the e-cigarette aerosol. In particular, we felt that the focus on determining the analytes on the US FDA's list of harmful and potentially harmful constituents (HPHC) in e-cigarette aerosols was too limiting as few were found and the list had been developed for the emissions from combustible tobacco products, and not those generated by e-cigarettes. Moreover, the analyses on e-liquids we had obtained and reported on previously indicated that toxicants might be generated when such e-liquids were aerosolized during use with e-cigarettes. Confirming that hypothesis could involve the use of *in vitro* toxicological assays as well as nonstandard aerosol collection systems. Thus, we needed a smoking machine with much space available for sampling equipment.

Smoking machine design and fabrication

The initial design called for a four-port CV smoking machine with the ports on 6-inch (15 cm) centers with an additional 6 inches of clearance between the end ports and the mounting points for the smoking bar. The smoking bar would be mounted on a 48-inch (122 cm) by 30-inch (76-cm) mobile ESD safety edge mobile workbench with a 1.25-inch (3.2 cm) top and a lower-level shelf (Global Equipment Co., Port Washington, NY 11050 USA). The vacuum source would be an existing 140 L/min Bestech direct-vane-type vacuum pump and flow to the smoke traps would be controlled through critical flow orifices (CFOs). Commercial smoke traps and mounting hardware would be used, and a nonmetallic smoking bar would need to be built. The puff off/on would be done with solenoid valves controlled by a USB relay board connected to a PC (Lauterbach & Lauterbach, 2014). Several problems were encountered and solved during the construction and testing of the machine. The use of CFOs was impractical due to cost and the need for three sets of CFOs to provide the flow rates needed for 3-second, 4-second, and 5-second 55 mL puffs. Swagelok SS-4MG-SL metering valves were used instead of CFOs. Flow to the smoke traps is controlled by a Sizto Tech (Palo Alto, CA 94303 USA) 2P025-1/8-1-G 1/8" NPT Direct-Acting 2-Way Plastic Solenoid Valve on the tubing leading to each smoke trap. The solenoid valves are controlled by an 8-channel USB relay board and PC software obtained from Denkovi Assembly Electronics LTD, Byala 7100, Bulgaria. Also, an 11-gallon (42-liter) vacuum surge tank was needed to minimize loss of vacuum during puffing. The smoking bar holding the smoke traps and mounting

Smoking machine design and fabrication (con't)

hardware was constructed from oak by Cabinet Concepts, Forsyth, GA 31029 USA. The smoke traps were obtained from Puffman Industries Co., Ltd., Shanghai City, China. The smoke traps were connected to the puffing system using eccentric housings and adjusting sleeves obtained from Cerulean, Richmond, VA 23228 USA. Flow rates at each port were measured using a 500-mL bubble meter (Sigma-Aldrich, St. Louis, MO 63103 USA).

Results and discussion

Initial evaluation of the smoking machine was conducted using brand-styles of rechargeable "cigalike" e-cigarettes purchased from Internet vendors (GreenSmoke, V2) or at retail (MarkTen). Figure 1 shows a typical smoking run.

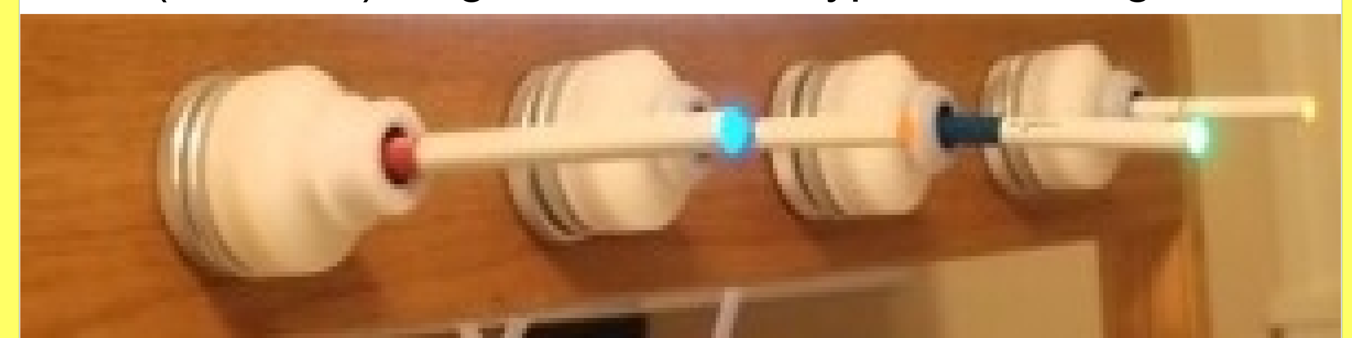
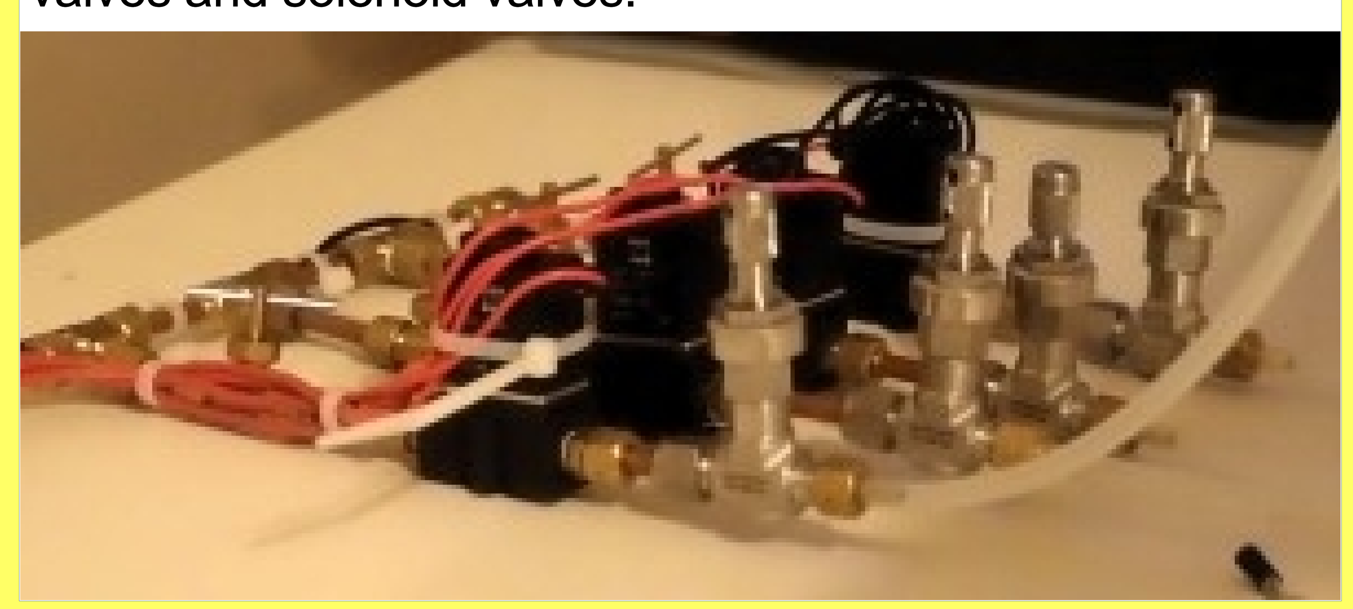


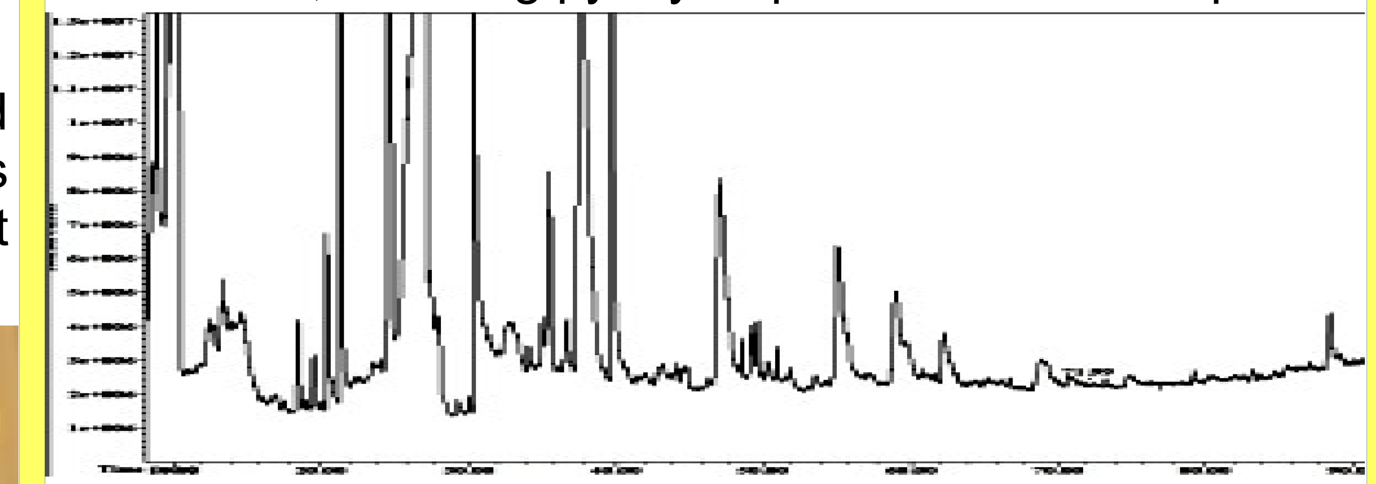
Figure 2 shows an overall picture of the smoking machine, not including the vacuum pump, surge tank, and power supply for the relays and solenoids below tabletop.

Figure 3 shows metering valve assembly with shutoff valves and solenoid valves.



Results and discussion (con't)

Figure 4 shows the GC-MS Total Ion Chromatogram of TPM collected from 25 4-second, 55 mL puffs of a clove-flavored e-cigarette. After collection of the e-cigarette aerosol, the Cambridge filter pad (CFP) was placed in a sealed vial and sent to a GC-MS laboratory. The CFP was treated with a 2:1 mixture of BSTFA/DMF, and the extract was chromatographed on a DB-5 column. This technique permits identification of compounds found in the aerosol, including pyrolysis products of the e-liquid.



Another aspect of our research is the visualization of the aerosol stream emitted by the e-cigarette as it is puffed. A glassmouth was used for these experiments. Two e-cigarettes were used, one with one hole on the mouth end, and the other had four holes on the mouth end. The images are shown in Figures 5 and 6, respectively.

Conclusions

In this brief poster presentation, we have shown some of the highlights of the design, construction, and use of our 4-port e-cigarette smoking machine. The original objectives of the project have been met. Additional reports on the performance and use of this machine will be made at future meetings and in journal articles.

References

A. B. Canon, 1976, http://industrydocuments.library.ucsf.edu/tobacco/docs/gllb0093.
W. E. Claflin & F. M. Watson, US Patent 4,019,366
M. Connor, 2013, TSRC, Paper 77.
J. Lauterbach & S. J. Lauterbach, 2014, CORESTA Congress, Paper ST41.
R. Newsome *et al*., 1965, Tobacco Science, 9, pp. 102-110.